METHOD OF MANUFACTURING ELECTRON-EMITTING DEVICE, ELECTRON SOURCE AND IMAGE-FORMING APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a method of manufacturing an electron-emitting device having an electroconductive film, an electron source realized by arranging a plurality of such electron-emitting devices on a substrate and an image-forming apparatus comprising the same.

Related Background Art

CRTs have been widely used for image-forming apparatus for displaying images by means of electron beams.

In recent years, on the other hand, flat panel display apparatus utilizing liquid crystal have been replacing CRTs to some extent. However, they are accompanied by certain drawbacks including that they have to be provided with a back light because they are not of an emissive type and hence there exists a strongdemand for emissive type display apparatus. While plasma displays have become commercially available as emissive type display apparatus, they are based on principles that are different from those of CRTs and can not fully compete with CRTs, at least currently, from the viewpoint of contrast, chromatic

effects and other technological factors. Since an electron-emitting device appears to be very promising for preparing an electron source by arranging a plurality of such devices and an image-forming apparatus comprising such an electron source is expected as effective as CRT for light emitting effects, efforts have been made in the field of research and development of electron-emitting devices of the type under consideration.

For instance, the applicant of the present invention has made a number of proposals for an electron source realized by arranging a number of surface conduction electron-emitting devices that are cold-cathode type devices and an image-forming apparatus comprising such an electron source.

Since the configuration and the characteristic features of a surface conduction electron-emitting device and those of an electron source comprising such devices are described in detail in various documents including Japanese Application Laid-Open No. 7-235255, they will be described only summarily here. FIGS. 4A and 4B of the accompanying drawings schematically illustrate a surface conduction electron-emitting device comprising a substrate 1, a pair of device electrodes 2 and 3 and an electroconductive film 4, which includes an electron-emitting region 5. With a method of producing an electron-emitting region, a part

of the electroconductive film is deformed, transformed or destroyed to make it electrically highly resistive by applying a voltage between the paired device electrodes. This process is referred to as "energization forming process". In order to produce an electron-emitting region that operates well for electron emission in an electroconductive film, the latter preferably comprises electroconductive fine particles such as fine particles of palladium oxide (PdO). A pulse voltage is preferably used for an energization forming process. A pulse voltage to be used for energization forming may have a constant waveheight as shown in FIG. 13A or, alternatively, it may have a gradually increasing waveheight as shown in FIG. 13B.

While an electroconductive film of fine particles may be prepared by means of a gas deposition technique, with which electroconductive fine particles are deposited directly on a substrate, a technique of applying a solution of a compound of the element that constitutes the electroconductive film (e.g., an organic metal compound) to a substrate and producing a desired electroconductive film typically by heat treatment is more advantageous particularly for preparing a large electron source because it does not require the use of a vacuum apparatus and hence is less costly. For applying a solution of an organic metal

compound only to an intended area, an ink-jet device may advantageously be used because it does not require any additional patterning operation for the electroconductive film.

After producing an electron-emitting region, a film containing carbon as principal ingredient is formed in the electron-emitting region and its vicinity by deposition to increase the intensity of electric current flowing through the device and improve the electron-emitting property of the device by applying a pulse voltage between the device electrodes in an appropriate atmosphere containing organic substances (a process referred to as "activation process").

Then, the electron-emitting device is preferably subjected to a process referred to as "stabilization process", where the device is placed and heated in a vacuum vessel while the latter is gradually evacuated in order to satisfactorily remove the organic substances remaining in the vacuum vessel and make the device operate stably.

Methods for producing electroconductive films for an electron source comprising surface conduction electron-emitting devices are disclosed in a number of documents including Japanese Patent Application Laid-Open No. 8-273529, the assignee of which is the applicant of the present patent application.

Now, ink-jet devices that can be used for the

purpose of the present invention will be briefly described below.

Ink-jet devices are roughly classified into two types according to the ink ejection technique used in the device.

According to a first ink ejection technique, fine liquid drops of ink is ejected by the pressure generated by contraction of a piezo-electric element arranged in a nozzle. A second technique is referred to as a bubble-jet system, with which ink is heated to bubble by means of a heat-generating resistor and then ejected in the form of fine liquid drops.

FIGS. 5 and 6 schematically illustrate ink-jet devices of these two types.

FIG. 5 shows a piezo-jet type ink-jet device comprising a first glass-made nozzle 21, a second glass-made nozzle 22, a cylindrical piezo-electric element 23, tubes 25 and 26 for feeding liquid to be ejected that may typically be a solution of an organic metal compound and an electric signal input terminal 27. As a predetermined voltage is applied to the electric signal input terminal, the cylindrical piezo-electric element contracts to discharge the liquid staying there as fine drops.

FIG. 6 shows a bubble-jet type ink-jet device comprising a base plate 31, a heat-generating resistor 32, a support plate 33, a liquid path 34, a first

nozzle 35, a second nozzle 36, a partition wall 37, a pair of liquid chambers 38 and 39 containing predetermined liquid, a pair of liquid supply ports 310 and 311 and a top plate 312. With this arrangement, the liquid in the liquid chambers is caused to bubble and forced out from the nozzles as liquid drops by the heat generated by the heat-generating resistor. While each of the above described devices has a pair of nozzles, the number of nozzles arranged in a device of the type under consideration is not limited to two.

After applying a solution of an organic metal compound only to predetermined areas as fine liquid drops by means of an ink-jet device of either of the above described types and then drying the solution, the organic metal compound is heated for pyrolysis to produce an electroconductive film typically made of fine particles of metal or metal oxide.

The produced electroconductive film has a thickness preferably between several and 50 nanometers, although it may vary depending on the electric resistance of the electroconductive film, the distance separating the device electrodes and other factors. The variance of the film thickness has to be strictly limited within a single electron-emitting device and also among the electron-emitting devices of an electron source.

An electron-emitting region may not be prepared

correctly and properly in an electron-emitting device if the electroconductive film of the electron-emitting device shows a large variance. Likewise, an electron source comprising a large number of electron-emitting devices showing a large variance in the film thickness of their electroconductive films may not operate evenly and uniformly for electron emission.

Therefore, the ink-jet device to be used for producing electroconductive films has to be examined and regulated thoroughly in order to ensure an even and uniform production of electroconductive films that are free from any undesirably variance in the film thickness.

A large and high definition flat-type image-forming apparatus can be manufactured only by using an electron source comprising a large number of electron-emitting devices that operate satisfactorily from the above described point of view.

Thus, while the ink-jet device being used for forming electroconductive films on respective electron-emitting devices is rigorously controlled for operation in order to avoid producing defective devices, the probability of producing defective devices inevitably rises as the number of electron-emitting devices arranged in an image-forming apparatus increases.

There can be various causes that give rise to

defective electroconductive films produced by means of an ink-jet device, including noises mingled into the electric signals for controlling the ink-jet device that interfere with the normal liquid drop ejecting operation of the device to make the film thickness of the produced electroconductive film significantly departing from a predetermined level, mechanical vibrations that displace the locations where liquid drops are applied on the electron source substrate and foreign objects put into the liquid contained in the ink-jet device to interfere with the normal liquid discharge of the device to make the produced electroconductive films unacceptable in terms of thickness, location and profile.

When manufacturing electron-emitting devices on a mass production basis, it is very difficult to improve the rate of producing acceptable devices or the manufacturing yield particularly when a large number of electron-emitting devices have to be produced on a single substrate.

A manufacturing yield is accompanied by high manufacturing cost and a need for treating rejected devices. In view of the current social need for suppressing the volume of industrial wastes, therefore, there is a strong and urgent demand for a method of manufacturing electron-emitting devices at a high yield.

SUMMARY OF THE INVENTION

Under the above described circumstances, it is therefore an object of the present invention to provide a method of manufacturing an electron-emitting device such as an surface conduction electron-emitting device having an electroconductive film including an electron-emitting region that can be used for rectifying a rejected electroconductive film to an acceptable one in the course of manufacturing the device.

Another object of the present invention is to provide a method of manufacturing an electron source comprising a plurality of electron-emitting devices that can remarkably improve the manufacturing yield by partially rectifying defective electroconductive films found in the devices in the course of manufacturing it the electron source.

Still another object of the present invention is to provide a method of manufacturing an image-forming apparatus comprising an electron source prepared by arranging a large number of electron-emitting devices that can effectively and remarkably improve the manufacturing yield and produce image-forming apparatus that are free from defective images and a noticeable variance in the brightness.

According to an aspect of the invention, the above object is achieved by providing a method of

manufacturing an electron-emitting device having an electroconductive film including an electron-emitting region arranged between a pair of device electrodes, characterized in that the process of forming an electroconductive film including an electron-emitting region comprises steps of applying a liquid containing the material of the electroconductive film to a substrate by an ink-jet method and thereafter detecting any defective condition in the applied liquid and applying the liquid containing the material again to the area detected for a defective condition in the applied liquid by an ink-jet method.

According to another aspect of the invention, there is provided a method of manufacturing an electron source comprising a plurality of electron-emitting devices arranged on a substrate, each having an electroconductive film including an electron-emitting region formed between a pair of device electrodes, characterized in that the electron-emitting devices are manufactured by the above described method.

According to still another aspect of the invention, there is also provided a method of manufacturing an image-forming apparatus comprising an electron source formed by arranging a plurality of electron-emitting devices on a substrate, each having an electroconductive film including an electron-emitting region formed between a pair of

device electrodes, and an image-forming section for forming an image by irradiation of electrons emitted from the electron source, characterized in that the electron-emitting devices are manufactured by the above described method.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A, 1B, 1C, 1D and 1E are schematic illustrations of a method of manufacturing an electron-emitting device according to the invention, showing steps of examining a precursor film, removing a defective precursor film and forming a replacement precursor film.

FIGS. 2A, 2B and 2C are schematic illustrations of a method of manufacturing an electron-emitting device according to the invention, showing an alternative step of removing a defective precursor film.

FIG. 3A is a graph showing the If-Vf relationship of an electron-emitting device accompanied by a leak current as a result of an energization forming process.

FIG. 3B is a graph showing the If-Vf relationship of an electron-emitting device properly subjected to an energization forming process.

FIGS. 4A and 4B are schematic illustrations of a surface conduction electron-emitting device, showing its configuration.

FIG. 5 is a schematic illustration of a piezo-jet

type ink-jet device, showing its configuration.

FIG. 6 is a schematic illustration of a bubble-jet type ink-jet device, showing its configuration.

FIG. 7 is a schematic illustration of a device for locally producing a reducing atmosphere.

FIGS. 8A, 8B, 8C, 8D and 8E are schematic illustrations of a process of forming an electron source with a matrix-wiring arrangement.

FIG. 9 is a schematic illustration of an image-forming apparatus manufactured by a method according to the invention.

FIG. 10 is a schematic illustration of a wiring arrangement to be used for an energization forming process.

FIGS. 11A, 11B, 11C, 11D and 11E are schematic illustrations of part of an electron source being processed for wiring by means of photolithography for the purpose of the invention.

FIG. 12 is a plan view of the electron source of FIGS. 11A through 11E, which shows cross sectional views taken along line A-A.

FIGS. 13A and 13B are graphs showing two different pulse voltage waveforms that can be used for an energization forming process for the purpose of the invention.

FIG. 14 is a graph showing the relationship between the film thickness and the sheet resistance of

a film of electroconductive fine particles.

FIG. 15 is a schematic illustration of an electron source having a ladder-like wiring arrangement.

FIG. 16 is a schematic illustration of an image-forming apparatus comprising an electron source as illustrated in FIG. 15.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, the present invention will be described in greater detail by referring to the accompanying drawings that illustrate preferred embodiments of the invention.

In an aspect, the present invention specifically relates to a method of manufacturing an electron source comprising a large number of electron-emitting devices arranged on a substrate, each having a pair of device electrodes oppositely disposed on the substrate and an electroconductive film connected to the paired device electrodes and including an electron-emitting region as part thereof, wherein the process of forming the electroconductive film for each electron-emitting device comprises steps of applying drops of a liquid containing the material of the electroconductive film to a predetermined area of a substrate by an ink-jet device and drying and thereafter heat-treating the applied liquid to produce a film of electroconductive fine particles and furthermore the following additional

steps.

In a first preferred mode of carrying out the invention, the additional steps are steps of examining a precursor film for forming a film of electroconductive fine particles (hereinafter simply referred to as "precursor film") produced as a result of the step of applying drops of the liquid by an ink-jet device, removing the film from the area determined to be defective as a result of the examining step and applying drops of the liquid again to the removed area. Now, these steps will be described by referring to FIGS. 1A through 1E.

Referring firstly to FIG. 1A, there are shown a substrate 1 for forming an electron source and a pair of device electrodes 2 and 3. Then, a precursor film 6 is formed between the paired device electrodes to electrically connect them. If the produced precursor film is displaced from its proper position, it is rectified by the above described method. More specifically, reference symbol 6' denotes a displaced precursor film that has to be rectified. Techniques that can be used for detecting abnormal conditions on the precursor film such as displacement include visual observation through an optical microscope. FIG. 1A also illustrates an arrangement for detecting abnormal conditions. Referring to FIG. 1A, there are shown a reflector 11, an ink-jet device 12 for discharging a

solvent for rectification and an imaging apparatus 13 including an image enlarging optical system. With such an arrangement, any defective precursor film can be detected and the solvent can be applied there for rectification, while the ink-jet device can be checked for proper positioning by means of the imaging apparatus at the same time. Any abnormal conditions including a defective profile and an abnormal film thickness of the precursor film and unusually large crystal grains of the metal compound that is the precursor of the electroconductive material of the electroconductive film can be detected along with any positional displacement of the precursor film by this detecting operation. A precursor film under such an abnormal condition is determined to be defective for the purpose of the invention.

Various techniques may be used for removing defective films.

With a first technique, the film formed by applying a solvent such as water or an organic solvent by means of an ink-jet device is expanded through dissolution and dilution. Although the film should not be expanded to get to any of the adjacently arranged devices, this technique can prove to be simple and effective if the device of the film is separated from the adjacent devices by a considerable space and the fine particles of the film are dispersed when dried and

heat-treated so that it can be expanded sufficiently to make it electrically unconductive if viewed globally.

The above described technique of removing a film will be described further by referring to FIGS. 1B through 1D. Firstly, drops 14 of the solvent are applied to the precursor film to be rectified as shown in FIG. 1B. Then, the puddle 15 of the solvent formed on the precursor film is expanded without allowing it to get to any of the adjacently located electron-emitting devices. When the solvent is dried, the amount of the remaining organic metal compound is negligible and, as shown in FIG. 1D, the profile of the device before the formation of the precursor film is substantially restored. With a method according to the invention, a precursor film is formed once again as shown in FIG. 1E after the defective one is removed through the above described steps.

Now, the relationship between the film thickness and the sheet resistance of the film of electroconductive fine particles will be discussed.

When an electroconductive thin film that can be used for the purpose of the invention is made of a material having a resistivity ρ and has a width w, a length l and a thickness t, the sheet resistance Rs of the film is used to define the electric resistance R of the film as determined between the longitudinal opposite ends of the film.

$R = Rs \cdot l/w$

If ρ and t are constant and does not have positional dependency, the sheet resistance Rs is expressed by the equation below.

$Rs = \rho/t$

Thus, Rs is inversely proportional to t if the average film thickness is sufficiently greater than the average diameter of the fine particles of the film. This is because the film of fine particles can be approximately regarded to be an evenly and continuously extending film for various calculations and the positional variance of the film thickness that may be small does not have any significance for the purpose of the invention.

However, if the average film thickness is approximately same as the average diameter of the fine particles of the film, the sheet resistance of the film is significantly affected by the local unevenness of the film arising from the fact that it is made of fine particles and the positional variance of the film thickness becomes not negligible relative to the average film thickness to make the sheet resistance greater than the value obtained by extrapolating the above relationship of inversely proportional to the film thickness.

As the average film thickness is reduced further, the resistance shows a sharp rise until the film

becomes totally unconductive if viewed globally because the fine particles of the film do not contact with each other in considerable portions thereof. Under this condition, clusters, each formed by a single fine particle or by a plurality of fine particles, become isolated as they do not connect with each other. It may not be appropriate to call it a "film" any more under such a condition but will nevertheless be called as such hereinafter for the sake of convenience if such a way of naming may not give rise to any misunderstanding.

FIG. 14 is a graph showing the relationship between the film thickness and the sheet resistance of a film of fine particles of palladium oxide (PdO) produced by using an aqueous solution of an organic palladium compound as will be described hereinafter by referring to Example 1-1 and other examples. In any of these examples, the film thickness was controlled by controlling the number of times of applying drops of the aqueous solution of the organic palladium compound or by further applying drops of water to the applied drops of the aqueous solution to expand the area occupied by the applied drops of the aqueous solution. The applied organic palladium compound was then turned to palladium oxide (PdO) by heat-treating it at 300°C for 12 minutes. In any specimen used in the examples, the palladium oxide (PdO) fine particles showed an

average particle diameter of 10±2nm. It was also found that the sheet resistance Rs was inversely proportional to the film thickness t when the average film thickness was greater than about 15nm but the actual values (indicated by the thick solid line in FIG. 14) became greater than the calculated values (indicated by the thin solid line in FIG. 14) obtained by extrapolating the above relationship when the average film thickness was almost as large as the average particle diameter. The sheet resistance of the film showed an abrupt rise to lose its electric conductivity when the film thickness became as small as 6nm. Therefore, the results of the examples as described hereinafter agree well with the above observation.

Thus, what is important for carrying out the present invention is apparently to determine the extent to which the precursor film is expanded. If the electroconductive film obtained by heat-treating a normal precursor film has a film thickness of t and a surface area of s and the precursor film is expanded to show an area of S by applying a solvent in an above described rectifying operation, the average thickness T of the "film" (which is in fact not a film) produced by the subsequent heat-treatment will be expressed by T=st/S. In order for the film not to globally show any electric conductivity, T has to be sufficiently smaller than the average particle diameter D of the fine

particles of the film. More specifically, T is preferably smaller than 60% of D.

The operation of applying drops of the solution for the second time may be conducted when the solvent applied in the above step is dried or after the normal precursor film is heat-treated to produce an electroconductive film. If drops of the solution are applied after a heat-treatment operation of the precursor film, the precursor film that is diluted and expanded by the applied solvent in the above step will become comprised of isolated fine particles and the solution will wet the substrate in a way same as it did when it was applied for the first time to make the rectified device operate properly like a device that operates well from the very beginning. If the device is locally exposed to a reducing gas to turn the electroconductive fine particles of the metal oxide into those of the pure metal, the fine particles will be coagulated further to increase their diameters and successfully make the film unconductive globally even when the expansion of the area of the precursor film by the application of the solvent is more or less restricted.

The film may be made more apt to dissolve to the solvent if the latter contains an appropriate ligand. In other words, an aqueous solution of a salt containing a ligand that can easily coordinate with the

metal atom of the metal compound consisting the precursor film can easily dissolve the precursor film. Preferably, a chelatable ligand is used for the above ligand for the purpose of the invention. Candidates for such a ligand include diamines, amino acids and dicarboxylic acids.

With a second technique for removing defective precursor films, after diluting the film with a solvent as with the above described first technique (FIG. 2A), the solvent is sucked and removed from the film. The operation of sucking the solvent can be carried out by means of a spongy piece of porous resin 16 fitted to the front end of a rod 17 as shown in FIG. 17 or alternatively by means of a syringe needle or a tube. The device shows the original profile as shown in FIG. 23 after removing the solution dissolving the precursor film so that another precursor film may be formed there. With this technique, electron-emitting devices may be arranged more densely than the case where the above described first technique is used. In other words, this technique is suited in cases where the puddle of the solvent cannot be sufficiently expanded and the first technique is not feasible.

In a second preferred mode of carrying out the invention, the additional steps are steps of examining the eletroconductive films produced by heat-treating the liquid drops applied by an ink-jet device, removing

the electroconductive films judged as defective in the examining step and applying liquid drops to the appropriate areas of the removed defective films and heat-treating them to produce replacing electroconductive films.

An optical microscope may be used for optically observing electroconductive films in the examining step. Alternatively, the electroconductive films may be examined by observing the electric resistance of each of the electron-emitting devices and this examining technique may work more sensitively than the optical observation technique for detecting any abnormal film thickness.

Since the electroconductive film is not soluble in the solvent at this stage, the technique of diluting the electroconductive film as described earlier by referring to the first mode of carrying out the invention cannot feasibly be used here. Thus, a technique of physically removing the electroconductive film is adopted in this second mode of carrying out the invention. For instance, a fine rod carrying a piece of a soft and adhesive substance such as silicon rubber may be used and pressed onto the electroconductive film to make it adhering to the silicon rubber in order to remove it.

The electroconductive film can be removed reliably if the electroconductive film is made less adherent to

the substrate. More specifically, if the electroconductive film is made of fine particle of an electrically conductive metal oxide, the adhesion of the electroconductive film can be reduced by chemically reducing the metal oxide to pure metal. If, for example, the electroconductive film is made of fine particle of palladium oxide (PdO), the oxide can easily be reduced to metal Pd by exposing it to a hydrogen containing atmosphere. While the reducing reaction may proceed at room temperature, it may be made to proceed more quickly if the electroconductive film is heated to about 150°C. The use of a dual nozzle structure as shown in FIG. 7 may appropriately be used for exposing only selected devices to reducing gas. The inner nozzle 41 of the dual nozzle structure is used to eject reducing gas, which is then sucked by the outer nozzle 42 of the dual nozzle structure. If the outer nozzle is made to suck reducing gas at a rate sufficiently greater that the rate at which gas is discharged from the inner nozzle, the flow 42 of reducing gas would not be dispersed and gas will flow only through an area close to the nozzle tip to produce a local reducing atmosphere. With such an arrangement, an electroconductive film 44 to be removed can be exposed to the local reducing atmosphere to reduce its adhesion to the substrate so that it may be removed without difficulty. A mixture gas containing hydrogen is

preferably used as reducing gas to which a film of fine particles of palladium oxide (PdO) is exposed. Alternatively, the reducing gas containing hydrogen may advantageously be diluted with inert gas such as rare gas or nitrogen gas to realize a hydrogen concentration of 1 to 2% because such a mixture gas is free from the risk of explosion because the hydrogen concentration is sufficiently low and hence no specific anti-explosion arrangement is required for the purpose of the present invention.

In a third preferred mode of carrying out the invention, the additional steps are steps of examining the electroconductive film on each of the electron-emitting devices formed on a substrate after applying drops of a solution of the material of the electroconductive film by means of an ink-jet device to produce the electroconductive film and carrying out an energization forming process to produce an electron-emitting region there with or without a subsequent activation process and forming an electroconductive film on each of the devices determined to be defective in the examining step by applying liquid drops there once again by means of the ink-jet device. If necessary, the electroconductive film may be removed prior to the step of applying liquid drops.

The above described activation process is a

process of applying a pulse voltage between the device electrodes of each of the electron-emitting devices formed on a substrate in an appropriate atmosphere containing an organic substance after producing an electron-emitting region in the electroconductive film of the device to produce a film of a deposit containing carbon as principal ingredient on and near the electron-emitting region in order to increase the electric current that flows through the device and improve the electron-emitting performance of the device.

As described above, while an optical microscope may be used for the examining step, each of the device can be examined by causing an electric current to flow through the device and observing the relationship (If-Vf relationship) between the voltage (device voltage) Vf applied to the device and the electric current (device current) If flowing through the device.

If the If-Vf relationship is observed for each of the electron-emitting devices in an examining step conducted after the completion of the activation process, a triangular pulse voltage to be used for driving the device in an ordinary operation of the electron source may be applied to it. A defective electron-emitting device may easily be detected if it shows an unusually large electric resistance or the device electrodes are short-circuited. A leak current

in the device may also easily be detected because the If-Vf relationship is ohmically affected. Otherwise, the device may show a deviation of the threshold voltage of the If-Vf relationship from normal value for many reasons, which can also be detected and identified.

If the examining step is conducted before the activation process by applying a voltage to be used for driving the device in an ordinary operation of the electron source, the value of If is very low and the fissure in the electron-emitting region can be broadened to adversely affect the electron-emitting performance of the device. However, since the device shows a non-linear I-V relationship with a threshold voltage sufficiently lower than the voltage causing the broadening of the fissure, the device may be judged to be acceptable if the threshold voltage is found within a given range and unacceptable if the voltage is not found within that range.

More specifically, a triangular pulse voltage slightly higher than the threshold voltage is applied to each of the devices of the electron source to see the I-V relationship of the device. As described above, any short circuiting between the device electrodes and a leak current existing in the device can be detected from the observed I-V relationship. Additionally the quadratic differential of the If-Vf

relationship is determined by calculation using the obtained data to find a peak value, which is taken for the threshold voltage and used to determine if the device is acceptable or not. Care should be taken to use data that are substantially free from noise for the calculation of determining the quadratic differential. If necessary, the observation should be repeated and the average of the observed values should be used to minimize the influence of noise. FIG. 3A shows a graph of the If-Vf relationship that is ohmically affected. It may be safe to assume that a leak current is flowing through the device that shows such a relationship. To the contrary, FIG. 3B shows a graph of the If-Vf relationship that is normal and also a graph of the values calculated for d^2If/dVf^2-Vf. The voltage Vth corresponding to the obtained peak value of the quadratic differential is used as the threshold voltage and the device is judged to be acceptable if the threshold voltage is found within a given range. Thus, while a sophisticated testing apparatus has to be used for determining the If-Vf relationship before the activation process, this technique is recommendable if it is expected that the operation of producing a second electroconductive film may have to be conducted frequently because it is free from the disadvantage of carrying out the activation process twice.

The step of removing the electroconductive film

from each of the electron-emitting devices that is determined to be defective in terms of short-circuiting and leak current is indispensable for the purpose of the invention. However, the electroconductive film does not necessarily be removed literally in this step if the fissure of the electron-emitting region has been unusually broadened for a reason or another, which may be an excessive electric current used in the energization forming process. If such is the case, liquid drops of the solution may simply be applied to the site of the electroconductive film to produce another electroconductive film, which is subsequently subjected an energization forming process.

Note that the second and third techniques may be used not only when a solution of a compound of the substance of the electroconductive film is applied by an ink-jet device but also when a solution containing dispersed electroconductive fine particles for forming the electroconductive film used.

If the above described third technique is used, the activation process may be carried out either before or after assembling the image-forming apparatus unless the examining step is conducted after the activation process. If the activation process takes place after assembling the image-forming apparatus, an appropriate organic gaseous substance is placed in the vacuum container of the image-forming apparatus and a pulse

voltage is applied repeatedly to the electron-emitting devices of the apparatus for the activation process. If, contrary, the activation process is conducted before assembling the image-forming apparatus, the electron source of the apparatus is placed in an appropriate vacuum apparatus with an appropriate gaseous substance and a pulse voltage is applied repeated to the electron-emitting devices of the apparatus.

The former procedure has an advantage that it does not require any additional vacuum apparatus, whereas the latter provides an advantage that no organic substance for the activation process has to be introduced into the vacuum container of the image-forming apparatus and hence the organic substance already existing in the vacuum container, if any, can easily be removed to stabilize the operation of the apparatus. Either of the above two procedures may be selected for the activation process by taking the actual manufacturing conditions into consideration. Organic substances that can be used for the activation process include acetone and n-hexane. Alternatively, an exhausting device that is not oil-free may be used to exploit the organic substance produced by the device.

It will be needless to say that the latter procedure is necessarily used when the examining step

is conducted by means of the third technique after the activation process.

The present invention include a method of manufacturing a flat-type image-forming apparatus comprising an electron source prepared by means of one of the above described first through third techniques.

[Examples]

Now, the present invention will be described further by way of examples.

[Example 1-1]

In this example, an electron source was prepared by following the steps as described below by referring to FIGS. 8A through 8E.

(Step-a)

After thoroughly cleansing a soda lime glass plate a silicon oxide (SiO_2) film was formed thereon to a thickness of 0.5μm by sputtering to produce a substrate 1, on which a resist layer is formed by applying photoresist (AZ1370: available from Hoechst Corporation) onto the substrate by means of a spinner. Thereafter, the photoresist was exposed to light and photochemically developed to produce a pair of openings corresponding to the contours of the device electrodes of each electron-emitting device to be formed on the substrate. Thereafter, Ti and Pt were sequentially deposited to respective thicknesses of 5nm and 50nm by sputtering and then the resist layer was removed with

an organic solvent to produce device electrodes 51 and 52 for each electron-emitting device by means of a lift-off technique. (FIG. 8A)

(Step-b)

A predetermined pattern of Ag paste was formed by screen printing and baked to produce Y-directional wires 53, each having a thickness of about 20μm and a width of 100μm. (FIG. 8B).

(Step-c)

A predetermined pattern of glass paste was formed by printing and baked to produce an interlayer insulation layer 54 for the devices of each row. Note that a cutout area 55 was formed for each device electrode 52 so that the latter was not covered by the interlayer insulation layer, which showed a width of about 250μm and a thickness of about 20μm in areas where it was laid on the Y-directional wires and about 35μm in the remaining areas. (FIG. 8C)

(Step-d)

A predetermined pattern of Ag paste was formed on the interlayer insulation layer 54 and baked to produce X-directional wires 56, each having a width of about 200μm and a thickness of 15μm. (FIG. 8D)

(Step-e)

Subsequently, drops of a solution of a complex of an organic palladium compound and an ethanol amine were applied to each electron-emitting device by means of a

piezo-jet type ink-jet device to produce a precursor film 57 for the electroconductive film of the device. Any adjacently located ones of the produced X-directional wires were separated by about 350μm, whereas any adjacently located ones of the Y-directional wires were separated by about 270μm. The precursor film had a substantially circular contour with a diameter of about 48μm. Drops of the solution were applied in such a manner that the produced precursor film showed a film thickness of about 15nm after a heat-treatment process, which will be described hereinafter. The precursor film contained fine particles with a diameter of about 10nm after the heat-treatment process conducted under the conditions as will be described hereinafter. (FIG. 8E)

FIG. 5 schematically illustrates an ink-jet device similar to the one used in this step, although only one of the paired nozzles was used for forming the precursor film.

(Step-f)

Each of the precursor films was observed by means of an image processing technique using a microscope and an optical sensor to automatically determine if the film is acceptable or not. Any film that carried one or more than one large crystals, that had been displaced from the proper position, that had been deformed and did not show a proper circular form or

that had a diameter exceeding 48μm or smaller than 32μm was determined to be unacceptable and drops of butyl acetate were applied to the defective area by means of the ink-jet device, using the nozzle that had not been used in the Step-e above. The ink-jet device was so regulated for the discharge of the solution that each drop showed a volume of about 60μm^3 and a total of ten drops were applied to each defective device to dissolve and dilute the defective precursor film in order to expand the film over the entire area surround by wires. Then, the solvent of butyl acetate was held to 120°C for 10 minutes for drying. As a result, the precursor film expanded to show an area about 13.5 times as large as the original area. Thus, the palladium oxide "film" obtained by heat-treating the film showed an average film thickness of about 1nm, which was sufficiently smaller than the average diameter of the fine particles of about 10nm. In other words, the precursor film expanded by the solvent did not significantly affected the subsequent steps.

(Step-g)

A precursor film was formed again on the area, from which the precursor film had been removed in the above step, under the conditions as described above for Step-e. The precursor film was observed through an microscope to confirm that it was acceptable this time.

(Step-h)

Then, the precursor film was heat-treated at 300°C for 10 minutes to produce an electroconductive film comprising fine particles of PdO.

(Step-i)

Then, the prepared electron source substrate (carrying thereon a plurality of pairs of device electrodes and electroconductive films arranged between the respective pairs of device electrodes) was used for produce an image-forming apparatus having a configuration as schematically illustrated in FIG. 9. After securing the electron source substrate 61 onto a rear plate 62 by means of frit glass, a face plate 63 (carrying a fluorescent film 65 and a metal back 66 arranged on the inner surface of a glass substrate 64) was arranged with a support frame 67 disposed therebetween and, subsequently, frit glass was applied to the contact areas of the face plate 63, the support frame 67 and the rear plate 62 and baked at 400°C in the atmosphere for 10 minutes to hermetically seal the container. In FIG. 9, reference numeral 68 denotes an electron-emitting device and numerals 69 and 70 respectively denote an X-directional device wire and a Y-directional device wire.

While the fluorescent film 65 is consisted only of a fluorescent body if the apparatus is for black and white images, the fluorescent film 65 of this example was prepared by forming black stripes in the first

place and filling the gaps separating them with stripe-shaped fluorescent members of primary colors. The black stripes were made of a popular material containing graphite as principal ingredient. A slurry technique was used for applying fluorescent materials onto the glass substrate 64.

A metal back 66 is typically arranged on the inner surface of the fluorescent film 65. After preparing the fluorescent film 65, the metal back 66 was prepared by carrying out a smoothing operation (normally referred to as "filming") on the inner surface of the fluorescent film 65 and thereafter forming thereon an aluminum layer by vacuum evaporation.

While a transparent electrode may be arranged on the face plate 63 on the outside of the fluorescent film 65 in order to enhance the electroconductive of the fluorescent film 65, no such transparent electrode was used in this example because the metal back provided a sufficient electroconductivity.

For the above bonding operation, the components were carefully aligned in order to ensure an accurate positional correspondence between the color fluorescent members 122 and the electron-emitting devices.

(Step-j)

The prepared glass container (hereinafter referred to as "envelope") was then evacuated by way of an exhaust pipe (not shown) to reduce the internal

pressure to less than 1.3×10^{-4}Pa, when an energization forming process was conducted in a manner as described hereinafter to produce an electron-emitting region in each of said plurality of electroconductive films. In the energization forming process, the Y-directional wires were connected to a common electrode 73 and applied to a voltage to the X-directional wires on a one-by-one basis as shown in FIG. 10. In FIG. 10, reference numerals 71 and 72 respectively denote X- and Y-directional wires, of which the Y-directional wires 72 are connected to the ground by way of a common electrode 73. An electron-emitting device 74 is arranged at each of the crossings of the X- and Y-directional wires. Reference numeral 75 denotes a pulse generator whose anode is connected to one of the X-directional wires while its cathode is connected to the ground by way of a resistor 76 for measuring the current intensity. Reference numeral 77 in FIG. 10 denotes an oscilloscope for monitoring the pulse current used for energization forming.

A voltage having a waveform was shown in FIG. 13B was used for the energization forming process.

Referring to FIG. 13B, the applied voltage was a triangular pulse voltage having a pulse width of T1=1msec and a pulse interval of T2=10msec and the waveheight (the peak voltage for energization forming) was gradually raised with step of 0.1V. During the

energization forming process, an extra pulse voltage of 0.1V was inserted into intervals of the energization forming pulse voltage in order to determine the resistance of the electron-emitting devices and the energization forming process was terminated when the resistance per device exceeded 100kΩ.

(Step-k)

Subsequently, acetone was introduced into the envelope to produce a pressure of 1.3×10^{-2}Pa in the inside of the envelope. Then, an activation process was carried out by applying a pulse voltage. The applied pulse voltage was a rectangular waveform having a wave height of 18V.

(Step-l)

The pressure in the inside of the envelope was evacuated for 10 hours to reduce the internal pressure to about 1.3×10^{-6}Pa, while maintaining the temperature of the entire envelope to 200°C.

After confirming that the apparatus operated properly for displaying images by matrix drive, the exhaust pipe (not shown) was welded by heating it with a gas burner to hermetically seal the envelope.

Finally, the envelope was subjected to a gettering process by means of high frequency heating.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness.

[Example 1-2]

The image-forming apparatus prepared in this example was same as that of Example 1-1 except that the plurality of electron-emitting devices were wired in a different way. More specifically, a ladder-like wiring arrangement was used for this example.

In this example, pairs of wires 95-a and 95-b were arranged on a substrate 91 and a plurality of paired device electrodes having respective electroconductive films prepared in a manner as described by referring to Example 1-1 were arranged between and connected to the wires and the substrate 91 was then put in an envelope provided with grid electrodes 96 having apertures 97 for allowing electrons to pass therethrough to produce an image-forming apparatus as in the case of Example 1-1. The image-forming apparatus operated as effectively as that of Example 1-1. Note that the components in FIG. 16 that are same as or similar to their counterparts of FIG. 9 are denoted by the same respective reference numerals.

[Example 2]

In this example, an image-forming apparatus was prepared by using the method of Example 1-1 except the following.

A bubble-jet type ink-jet device was used for applying liquid drops as described in Step-e of Example 1-1. The ink-jet device had a configuration as shown

in FIG. 6. In this example, one of the nozzles 35 and 36 was used for applying drops of an organic palladium solution, which solution was prepared by dissolving palladium acetate-monoethanole amine (PAME) into water to make the solution contain metal by 2wt%.

Additionally, drops of water were applied to the precursor films that had been judged as unacceptable in Step-f of Example 1-1 in order to dissolve the films. Drops of water were applied through the nozzle not used in Step-e.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness as in the case of Example 1-1.

Note that an aqueous solution of palladium acetate may also be used for this example.

Similarly, butyl acetate may be used as solvent for dissolving defective precursor films as in the case of Example 1-1. The volume of liquid drops to be applied may be halved if the number of times of liquid drop application is doubled to produce a same effect. The above described procedures may also be used for preparing an electron source having a ladder-like wiring arrangement described in Example 1-2.

[Example 3-1]

In this example, not only device electrodes but wires were also formed by photolithography. The

procedures of preparing an image-forming apparatus in this example will be described by referring to FIGS. 11A through 11E and FIG. 12, of which FIG. 12 is a schematic plan view of the electron source of this example and FIGS. 11A through 11E are sectional views taken along line A-A in FIG. 12. Note that the interlayer insulation layer and the contact holes are omitted in Fig. 12.

(Step-a)

After thoroughly cleansing a soda lime glass plate, a silicon oxide film was formed thereon to a thickness of 0.5μm by sputtering to produce a substrate 81. Then, a Cr film and an Au film were sequentially formed on the substrate to thicknesses of 5nm and 600nm respectively by vacuum evaporation, on which photoresist (AZ1370: available from Hoechst) was applied, while rotating the substrate, by means of a spinner and then baked. Thereafter, a photomask image was exposed and photochemically developed to produce a mask for Y-directional wires (lower wires) and then the Au/Cr depostion film was wet-etched to obtain Y-directional wires (lower wires) 82 having a desired pattern. (FIG. 11A)

(Step-b)

An interlayer insulation layer 83 of silicon oxide film was deposited to a thickness of 1.0μm by RF sputtering. (FIG. 11B).

(Step-c)

Subsequently, a photoresist pattern was formed on the silicon oxide film for contact holes 84 to be produced through the deposited silicon oxide film in Step-b and, using the resist pattern as a mask, contact holes 84 were actually prepared by etching the interlayer insulation layer 83 by means of RIE (Reactive Ion Etching). CF_4 and H_2 were used as etching gas. (FIG. 11C)

(Step-d)

Thereafter, a pattern of photoresist (RD-2000N-41: available form Hitachi Chemical Co., Ltd.) was prepared for device electrodes 51 and 52 showing a gap L between the device electrodes and Ti and Ni were sequentially deposited to respective thicknesses of 5nm and 100nm by vacuum evaporation. Then, the photoresist pattern was dissolved into an organic solvent and the Ni/Ti deposition layers were lifted off to produce pairs of device electrodes 51 and 52, having a width of 300μm and separated by a gap of 3μm. (FIG. 11D)

(Step-e)

Then, a photoresist pattern was prepared for X-directional wires (upper wires) 85 on the device electrodes 51 and 52 and Ti and Au were sequentially deposited to respective thicknesses of 5nm and 100nm by vacuum evaporation. Then, any unnecessary areas of the photoresist were removed by means of a lift-off

technique to produce upper wires 85. (Fig. 11E).

(Step-f)

Liquid drops were applied as in Step-e of Example 1-1 to produce precursor films. A solution of organic palladium (ccp-4230: available from Okuno Pharmaceutical Co., Ltd.) was used.

(Step-g)

Each of the precursor films was observed by means of a microscope. Any film that carried one or more than one large crystals, that had been displaced from the proper position, that had been deformed and did not show a proper circular form or that had a diameter exceeding 48μm or smaller than 32μm was determined to be unacceptable and drops of butyl acetate were applied to the defective area by means of the ink-jet device, using the nozzle that had not been used in the Step-e above. The ink-jet device was so regulated for the discharge of the solution that each drop showed a volume of about $60\mu m^3$ and a total of ten drops were applied to each defective device to dissolve and dilute the defective precursor film in order to expand the film over the entire area surround by wires. Then, the solvent of butyl acetate was left for drying and thereafter heat-treated at 300°C for 10 minutes. As a result of the heat-treatment, the precursor films of the acceptable devices turned to so many electroconductive films of PdO fine particles. The

treated areas came to show high electric resistance.

(Step-h)

A precursor film was formed again on the area, from which the precursor film had been removed in the above step, under the conditions as described above for Step-f. The precursor film was observed through an microscope to confirm that it was acceptable this time. While the precursor film produced for the second time in Example 1-1 showed a diameter that was acceptable but slightly greater than a precursor film that was accepted in the first examining step. This may be because the solution applied for the second time was apt to be expanded more than the solution applied for the first time as a thin film of the organic palladium compound was already there. Contrary to this, the precursor film formed for the second time showed a contour substantially same as the one formed for the first time. This may be because the dispersed organic palladium compound had turned to coagulated PdO particles to ensure a same level of wetability of the substrate both to the liquid drops applied for the first time and to the drops applied for the second time.

(Step-i)

Then, the precursor film was heat-treated at 300°C for 10 minutes to produce an electroconductive film comprising fine particles of PdO.

The following steps were same as those of Example 1-1.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness as in the case of Example 1-1.

[Example 3-2]

In this example, the steps of Example 3-1 were followed to produce an image-forming apparatus except that a bubble-jet type ink-jet device was used here to obtain a comparable result.

[Example 4]

In this example, the steps of Example 2 were followed except the following.

The acceptable precursor films showed a diameter of 80μm, or a twice as large as that of their counterparts of Example 2. They showed a film thickness of 30μm. If these films had been treated as in Example 2, no acceptable electroconductive films would have been produced out of them because the average film thickness could not be sufficiently small.

Liquid drops of a solvent were applied to the precursor films rejected in the examining step to dissolve and expand the films by means of a bubble-jet type ink-jet device. A 5wt% aqueous solution of ammonium salt of ethylenediaminetetraacetate (EDTA) was used for the solvent. It contained ligands that were

coordinated with Pd ions so that it could dissolve the precursor film more quickly than water.

After heat-treating the electron source at 300°C for 10 minutes, the defective electron-emitting devices were locally exposed to a reducing atmosphere, maintaining the electron source to about 150°C, by means of a dual nozzle structure as described earlier by referring to FIG. 7. The reducing atmosphere contained a mixture gas prepared by diluting hydrogen gas H_2 with nitrogen gas N_2 to show a hydrogen concentration of 2%. Since the explosible lower limit of hydrogen gas concentration in air is 4%, the above mixture gas could be used without any special anti-explosion arrangement if the manufacturing facility was ventilated well.

As a result of the above process, the related PdO fine particles turned to Pd fine particles that subsequently coagulated to become large particles so that they did not show globally any electroconductivity.

All the remaining steps were same as those of Example 2.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness as in the case of Example 2.

[Example 5-1]

In this example, Step-a through Step-e of Example 1-1 were followed except that the conditions were so selected in this example to produce precursor films having a diameter of 80μm. Since the defective precursor films had a large diameter and could not be expanded sufficiently in this example by dissolving it with a solvent, the following step was required.

(Step-f)

Liquid drops of a 5wt% aqueous solution of EDTA as used for Example 4 above were applied to the precursor films determined to be unacceptable through a microscopic observation and the solution containing the dissolved precursor films was sucked by pressing a rod provided with a piece of polyester sponge to each defective area.

The following steps were same as those of Example 1-1.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness as in the case of Example 1-1.

Electron-emitting devices can be arranged highly densely with the procedures of this example to produce a high definition image-forming apparatus. The possibility of generating a leak current that can become unnegligible if the defective precursor films were simply dissolved by a solvent can be eliminated by

completely removing the defective precursor films.

[Example 5-2]

In this example, the steps of Example 5-1 were followed to produce an image-forming apparatus except that a bubble-jet type ink-jet device was used here to produce an image-forming apparatus as effective as its counterpart of Example 5-1.

[Example 6-1]

In this example, the steps of Example 5-1 were followed except the following.

Liquid drops of the solvent were applied to the precursor films determined as defective by an examining step as Step-f of Example 5-1 and thereafter the solution containing the dissolved precursor films was sucked by means of a syringe needle connected to an exhaust apparatus by way of a silicon tube.

While a relatively large manufacturing apparatus had to be used for this example if compared with Example 5-1 but the above arrangement was effective for continuous manufacturing operation without replacing the sponge and hence suitable for mass production.

The technique of this example can be applied to an electron source having a ladder-like wiring arrangement described in Example 1-2 to achieve a similar result.

[Example 6-2]

In this example, the steps of Example 6-1 were followed to produce an image-forming apparatus except

that a bubble-jet type ink-jet device was used here to produce an image-forming apparatus as effective as its counterpart of Example 6-1.

[Example 7]

In this example, device electrodes were prepared by offset printing while wires were formed by screen printing.

(Step-a)

After thoroughly cleansing a soda lime glass plate, a silicon oxide (SiO_2) film was formed thereon to a thickness of 0.5μm by sputtering to produce a substrate 1. Then, a pair of device electrodes 51 and 52 were formed for each electron-emitting device by offset printing using Pt resinate paste. The device electrodes were separated by a gap of 50μm. (See FIG. 8A.)

Then, Step-b through Step-d of Example 1-1 were followed.

(Step-e)

Liquid drops of an aqueous solution of PAME as used in Step-e of Example 2 was applied to each electron-emitting device to produce a precursor film of an electroconductive film by means of a bubble-jet type ink-jet device. The conditions of this step were so selected as to produce circular precursor films having a diameter of 100μm. Then, the precursor films were heat-treated at 300°C for 10 minutes to produce

electroconductive films of PdO fine particles.

(Step-f)

The electric resistance of each electron-emitting device was observed and those having a resistance deviated from a reference value by more than 20% were rejected.

A rod provided with a piece of silicon rubber having a diameter of 200μm and a thickness of 500μm was pressed against each defective electron-emitting device to cause the silicon rubber to suck the electroconductive film, which was then removed.

(Step-g)

An electroconductive film was formed as in Step-e to replace the removed electroconductive film.

The following steps were same as those of Example 1-1.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness as in the case of Example 1-1.

[Example 8]

In this example, the steps of Example 7 were followed except the following.

Each of the electroconductive films determined as defective in Step-f of Example 7 was chemically reduced with the technique used in Example 4 and then the solution of the reduced substance was sucked and

removed by using a silicon rubber in a manner as described in Example 7.

The effect of the chemical reduction is that the electroconductive film could reduce the adhesion to the glass substrate by reducing the PdO fine particles of the electroconductive film to metal Pd so that the film could be removed easily and surely by pressing the silicon rubber against it.

[Example 9]

After following Step-a through Step-e of Example 7, the following steps were conducted.

(Step-f)

An electron source substrate prepared by following Step-a through Step-e of Example 7 was placed in a vacuum chamber, which was then evacuated to a pressure level lower than 1.3×10^{-4}Pa. The exhaust system used here was an ultra-high vacuum system comprising an ion pump as main pump and a scroll pump as an auxiliary pump.

Then, the electron source was subjected to an energization forming process in a manner as described for Step-j of Example 1-1 to produce an electron-emitting region in each of the electroconductive films.

(Step-g)

Subsequently, acetone was introduced into the vacuum chamber to a pressure level of 1.3×10^{-2}Pa and the

electron source was subjected to an activation process in a manner as described for Step-k of Example 1-1.

(Step-h)

The vacuum chamber was evacuated for 10 hours to a pressure level of less than 1.3×10^{-6}Pa, while heating it to about 200°C. Subsequently, a triangular pulse voltage with a waveheight of 18V was applied sequentially to the electron-emitting devices to observe the device current If and the corresponding device voltage Vf of each device.

While most of the electron-emitting devices showed a non-linear If-Vf relationship having a threshold value close to 10V. The device current If of each device was very small below the threshold value. More specifically, If=1.4-1.7mA for Vf=18V. However, some of the large number of electron-emitting devices prepared in a same way showed an ohmic effect, while other did not show any significant If for Vf=18V. Each of these devices was rejected as defective along with the devices that showed a value less than 1.2mA for If at Vf=18V.

(Step-i)

The electron source was then taken out from the vacuum chamber and the electroconductive film of each of the defective electron-emitting devices was chemically reduced and removed as in Example 8 and the above steps were repeated to produce an electron source

free from defective electron-emitting devices.

(Step-j)

An envelope was prepared as in Step-i of Example 1-1. Then, the envelope was evacuated and the exhaust pipe was welded before the envelope was subjected to a gettering process to produce an image-forming apparatus as in Step-l of Example 1-1.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness as in the case of Example 1-1.

[Example 10]

In this example, Step-a through Step-e of Example 7 and Step-f of Example 9 were followed. Thereafter, the following steps were conducted.

(Step-g)

After the above steps, a triangular pulse was applied sequentially to the electron-emitting devices to observe the device current If and the corresponding device voltage Vf of each device. The triangular pulse had a waveheight of 12V.

A total of 100 pulses were applied to each device to obtain the average of the observed values in order to eliminate the effect of noise. Then, the quadratic differential of the If-Vf relationship was determined by calculation using the obtained data to find a peak value for Vf, which was then taken for the threshold

voltage Vth. All the devices with Vth=10.0±1.0 were accepted whereas the remaining devices were rejected. While the devices were mostly acceptable, some of a large number of electron sources prepared in this example contained defective electron-emitting devices.

(Step-h)

The electron source was taken out from the vacuum chamber and each of the rejected electroconductive films was microscopically observed. Some of the rejected electroconductive films showed a large fissure for the electron-emitting region. An electron-emitting device with an electroconductive film having such a fissure did not show detectable If. The electron-emitting device of such a defective device was not removed and another electroconductive film was formed thereon.

Some of the remaining defective electron-emitting devices had a defective electron-emitting region and the electroconductive film was not completely separated into portions by a fissure to show a continuous electroconductive film, whereas others were carrying a foreign object adhering thereto or only a part of the electron-emitting region showed a large fissure. These defective electroconductive films were removed and replaced by new ones to produce a flawless electron source as in the case of Example 8.

(Step-i)

An envelope was prepared as in Step-k of Example 1-1. Then, acetone was introduced into the envelope for an activation process.

(Step-k)

The envelope was evacuated to show a high degree of vacuum and the exhaust pipe was welded before a gettering operation to produce an image-forming apparatus as in Step-l of Example 1-1.

The produced image-forming apparatus operated excellently for displaying images without noticeable unevenness in the brightness as in the case of Example 1-1.

[Advantages of the Invention]

As described above, according to the invention, in the process of manufacturing electron-emitting devices such as surface conduction electron-emitting devices, each comprising a pair of device electrodes and an electroconductive film including an electron-emitting region arranged between the device electrodes, any defective electroconductive films can be rectified or replace by flawless devices to improve the manufacturing yield. Particularly, in the case of an electron source comprising a plurality of electron-emitting devices, some of the electron-emitting devices that are found to be defective can be locally rectified so that the operation of manufacturing image-forming apparatus

comprising such electron sources can be conducted with a high yield to display fine images without noticeable unevenness in the brightness.